American Society for Gravitational and Space Research
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Evaluation of Primary Dendrite Arm Spacings from Aluminum-7wt% Silicon alloys Directionally Solidified aboard the International Space Station – Comparison with Theory

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MICAST

A NASA and European Space Agency (ESA) Collaboration:

Microstructure Formation in Castings of Technical Alloys under Diffusive and Magnetically Controlled Convective Conditions

- A systematic analysis of the effect of convection on the microstructural evolution in the directional solidification (DS) of engineering alloys.

- Experiments are carried out under well defined processing conditions.

- Sample analysis conducted using advanced diagnostics and theoretical modeling.

Previous Investigation

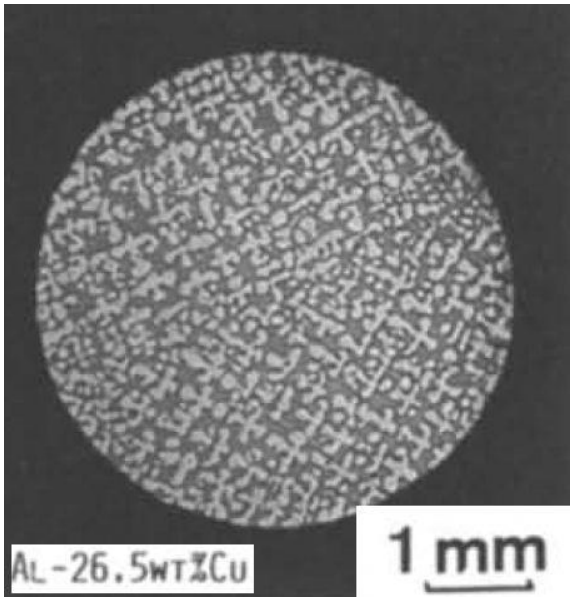
Al-26.5 wt. % Cu: Primary dendrite arm spacing increases in microgravity

30 K cm^{-1} , 4.2 μm s^{-1}

Terrestrial: Solutally unstable

Primary spacing = 450 ± 20 μm

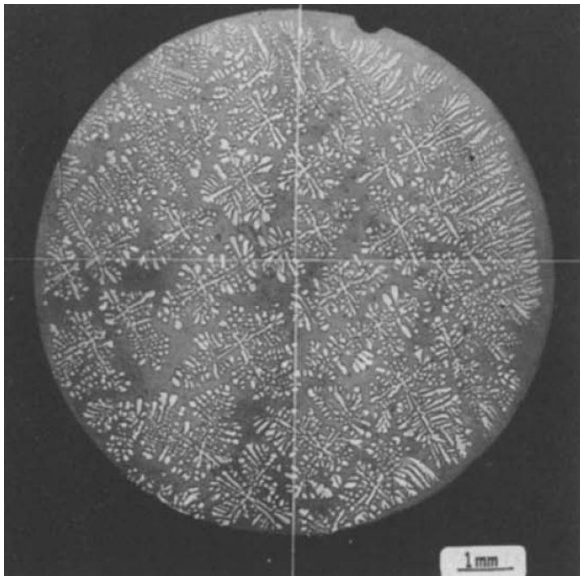
25 K cm^{-1} , 4.2 μm s^{-1}



Terrestrial: Solutally stable

34 0 ± 10 μm

30 K cm^{-1}, 4.2 μm s^{-1}



Microgravity

1540 ± 10 μm

(M.D. Dupouy, D. Camel and J.J. Favier, Acta. Metall. Mater. Vol. 37, No. 4, pp. 1143-1157, 1989)

Microgravity Processing

- Rods of Al-7Si cast at Alcoa Technical Center
- DS-ed at CSU to obtain aligned dendritic structure
  <100> parallel to axis
- Precision machined and shipped to ESA-contractor
- Inserted into alumina "crucible-molds"
- Put into Sample-Cartridge-Assembly (SCA)

Microgravity Science Research Facility (MSRF) aboard the ISS

Expectations:
Solidification Processing in a Microgravity Environment

Advantages: Mitigate Thermo-Solutal Convection

Intent: DS Samples under Diffusion-Controlled Conditions that are Free of Macrosegregation

Purpose: Better Understand the Relationship between Processing and Microstructural Development

Application: Benchmark measurements applicable to modeling efforts, improve ground-based processing

Comparison of ISS and Ground-based Experiments

MICAST6 / 6Ground

- DS growth rate increase (5 $\mu m\ s^{-1}$ to 50 $\mu m\ s^{-1}$)
- Temperature gradient: ~20 K/cm

MICAST7 / 7Ground

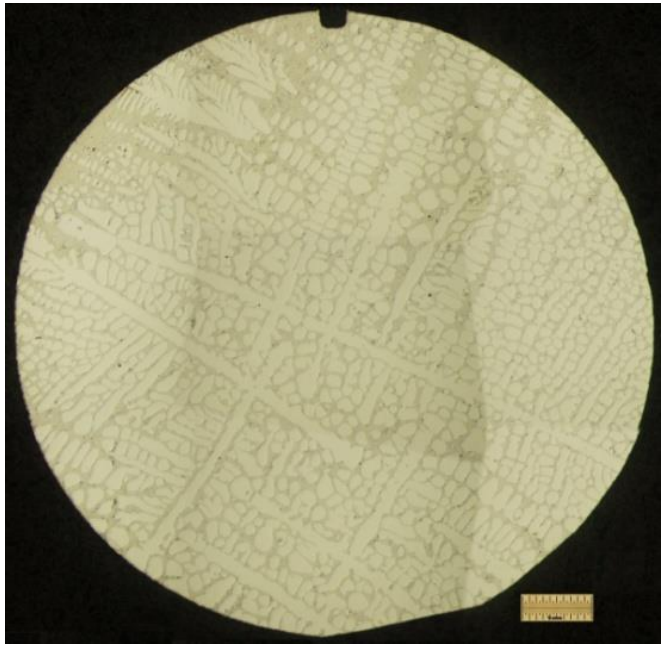
- DS growth rate decrease (20 $\mu m\ s^{-1}$ to 11 $\mu m\ s^{-1}$)
- Temperature gradient: ~26 K/cm

(MICAST12, Constant growth rate is currently being evaluated)

Microstructural Comparison: Earth and Microgravity

Terrestrial:
Al – 7wt.% Si
***G* = 15 K cm^{-1}**

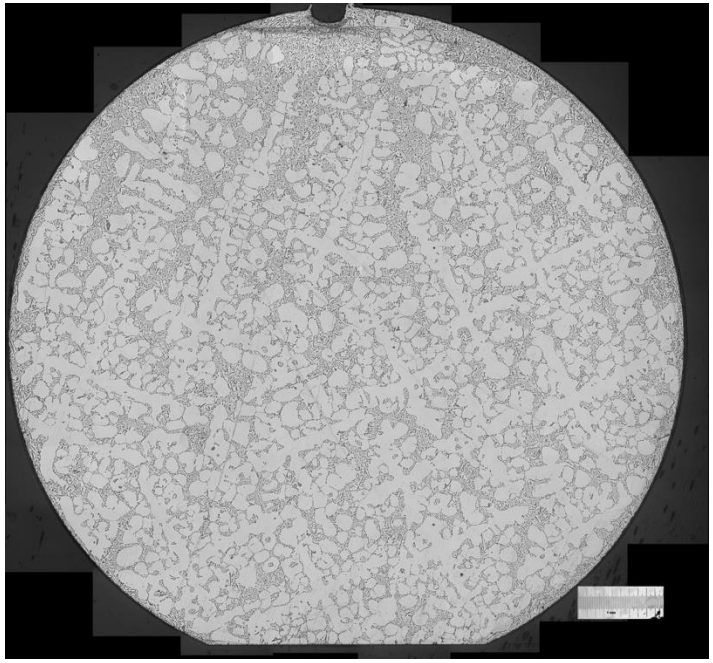
***V* = 5 μm s^{-1}**



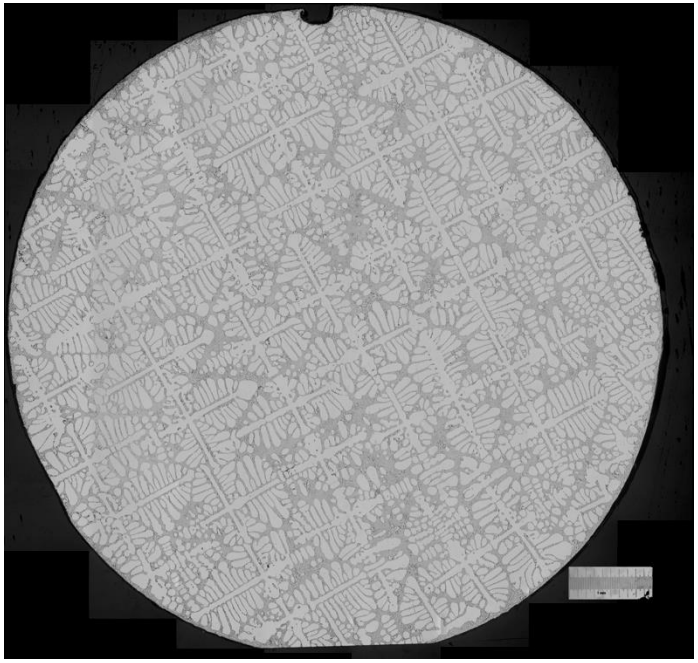
***V* = 50 μm s^{-1}**

Microstructural Comparison: Earth and Microgravity

MICAST6:
Al – 7wt.% Si
***G* = 20 K cm^{-1}**



***V* = 5 µm/s**



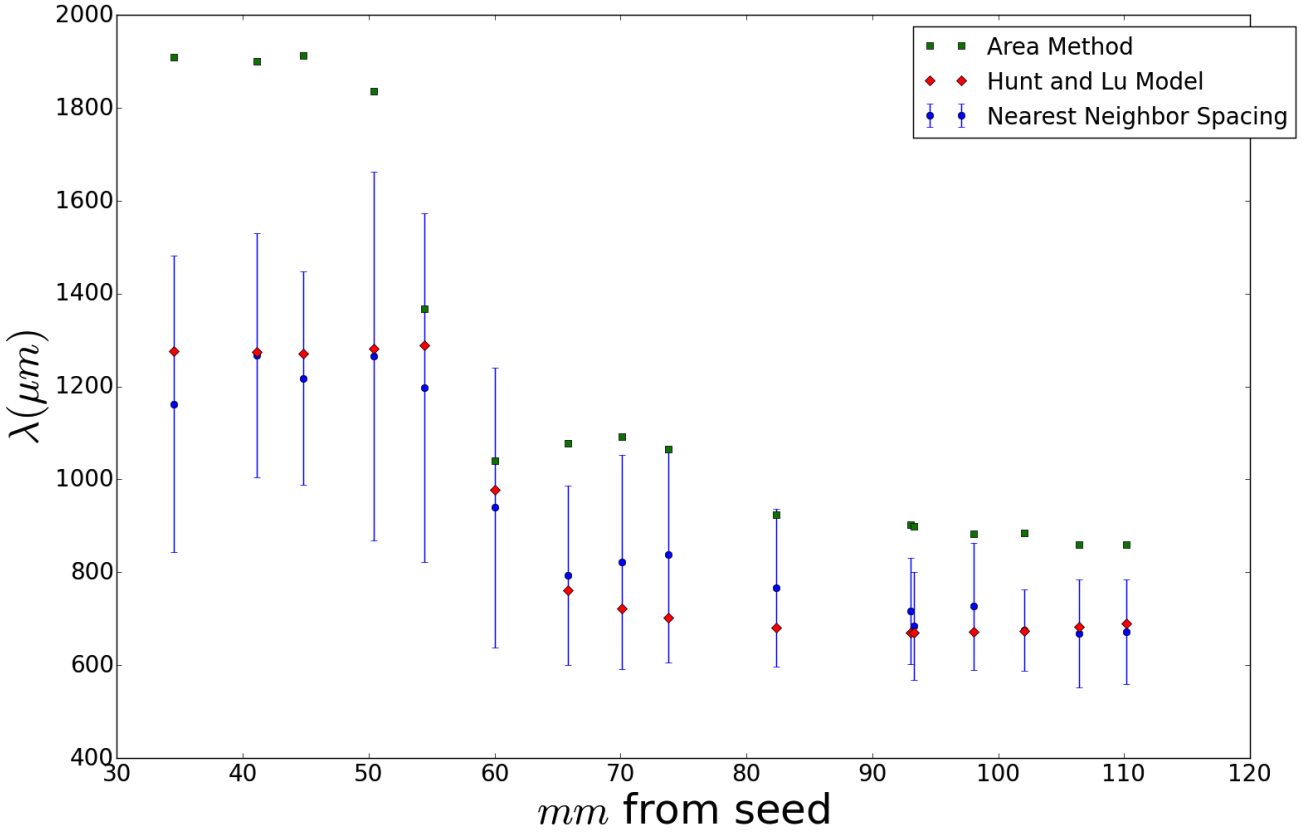
***V* = 50 µm/s**

Theoretical Model (diffusion-controlled growth), J.D. Hunt and S.-Z. Lu, 1996

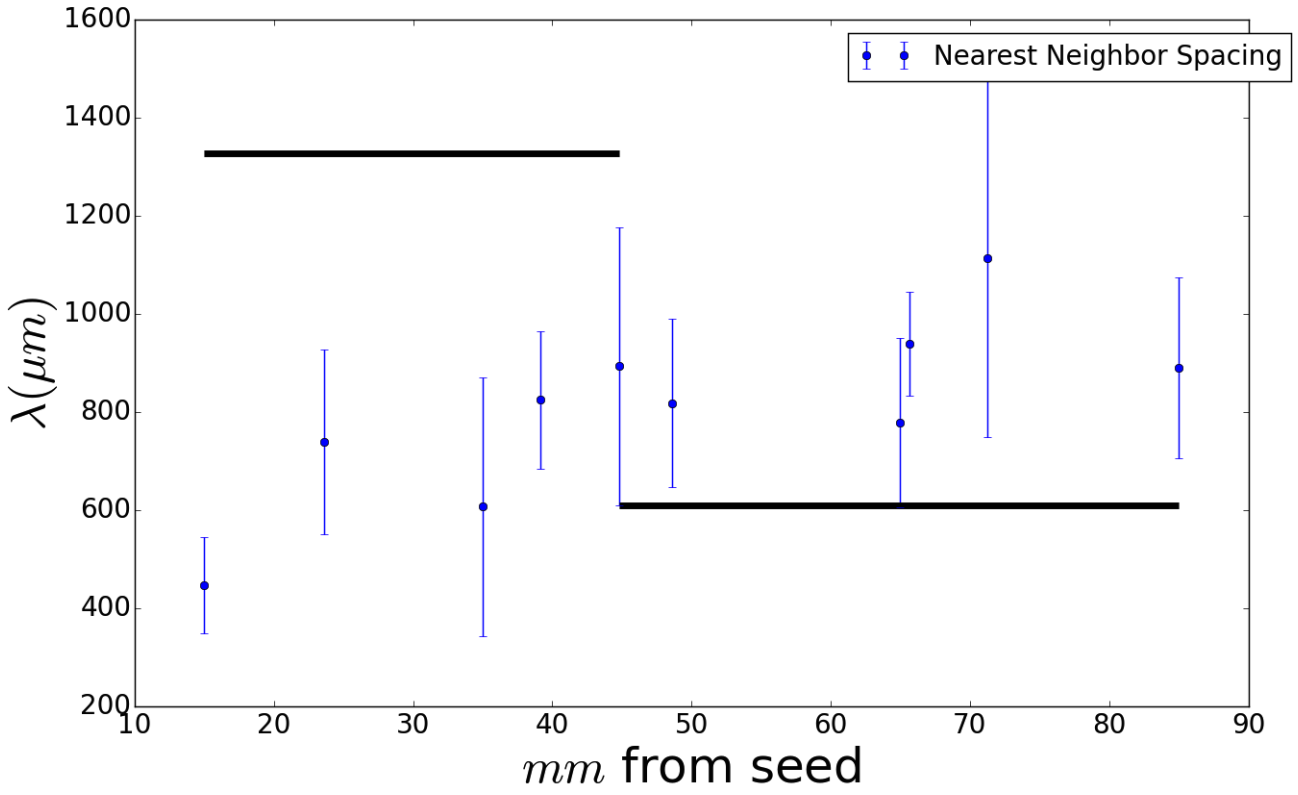
- Based on diffusion in the liquid around the dendrite tip.
- Calculates PDAS assuming no convection in the liquid.
- Physical constants for Al-7Si are well known.
- Final Equation: $\lambda' = 0.15596 V'^{(\alpha - 0.75)} (V' - G')^{0.75} (G')^{-0.6028}$
- Calculates the spacing as the tip-to-tip spacing.

J.D. Hunt and S.-Z. Lu: Numerical modeling of cellular/dendritic array growth: spacing and structure predictions, *Metall. Mater. Trans. A* **27A**, 1996, 611-623.

MICAST6- Primary Dendrite Arm Spacing



MICAST6G- Primary Dendrite Arm Spacing



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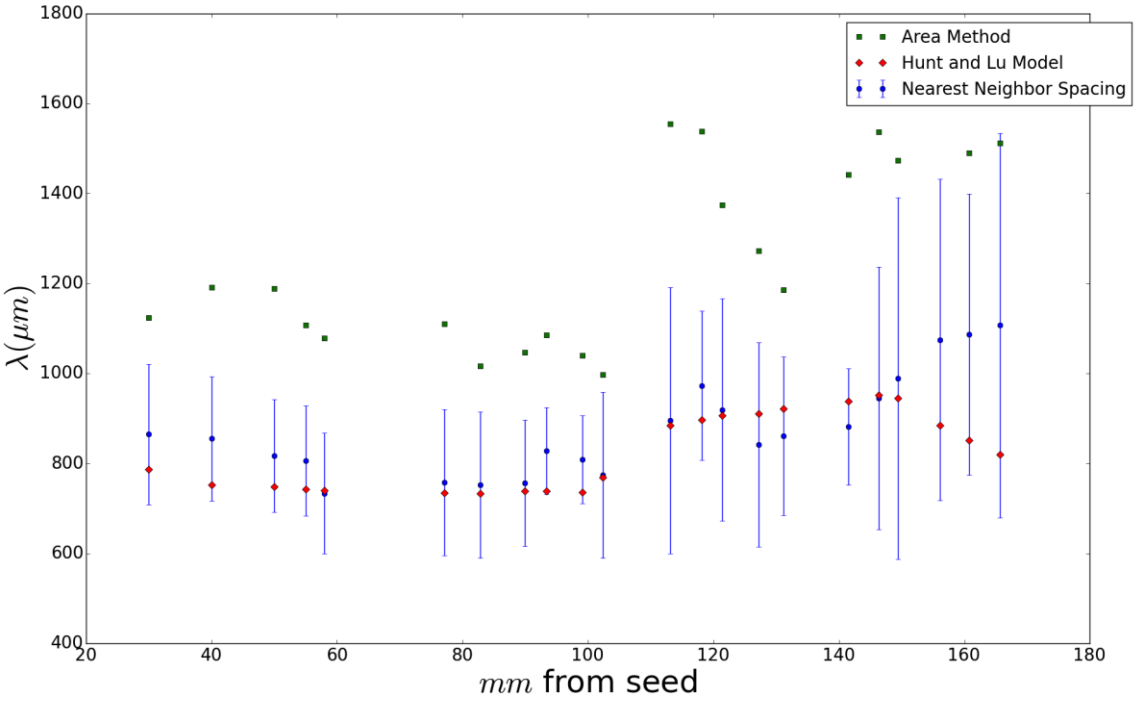
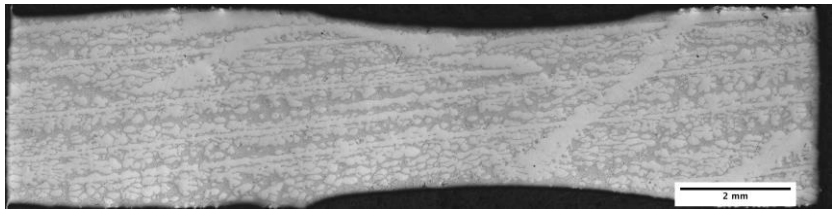
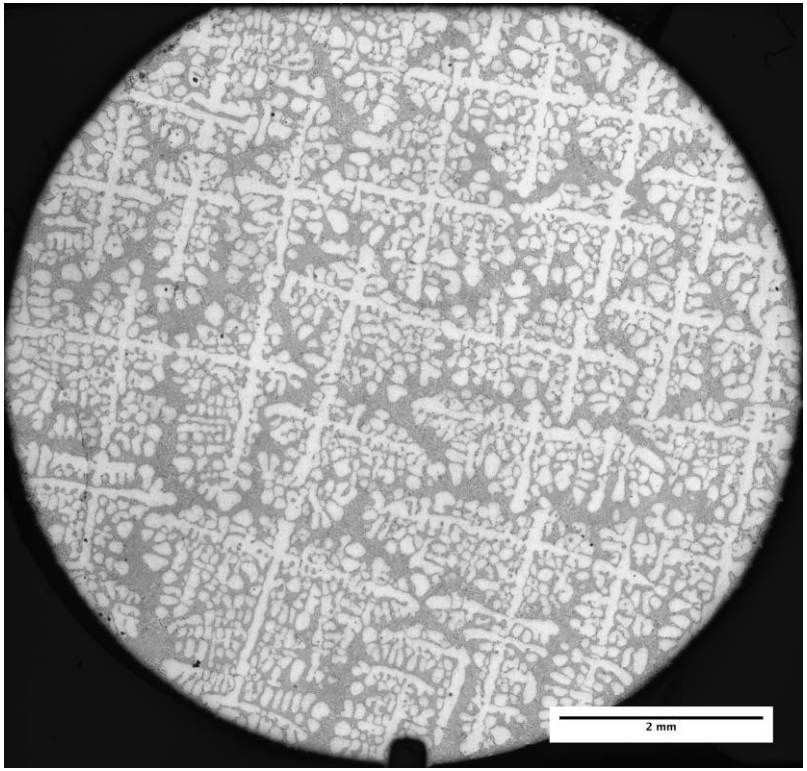
MICAST7- Primary Dendrite Arm Spacing



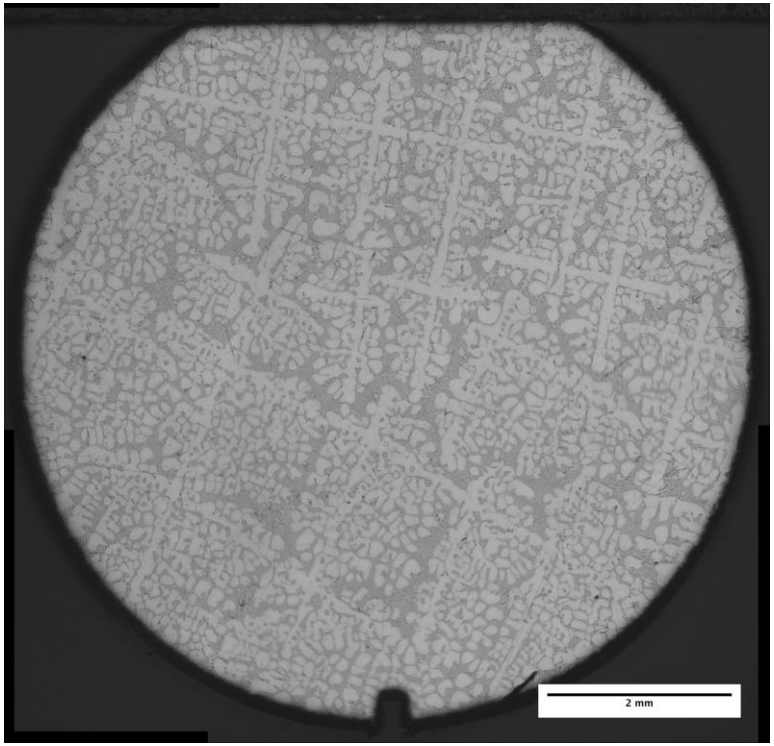
Separation may result in Marangoni convection in the liquid during DS at 60mm mark.



Marangoni Convection Effect- Continued

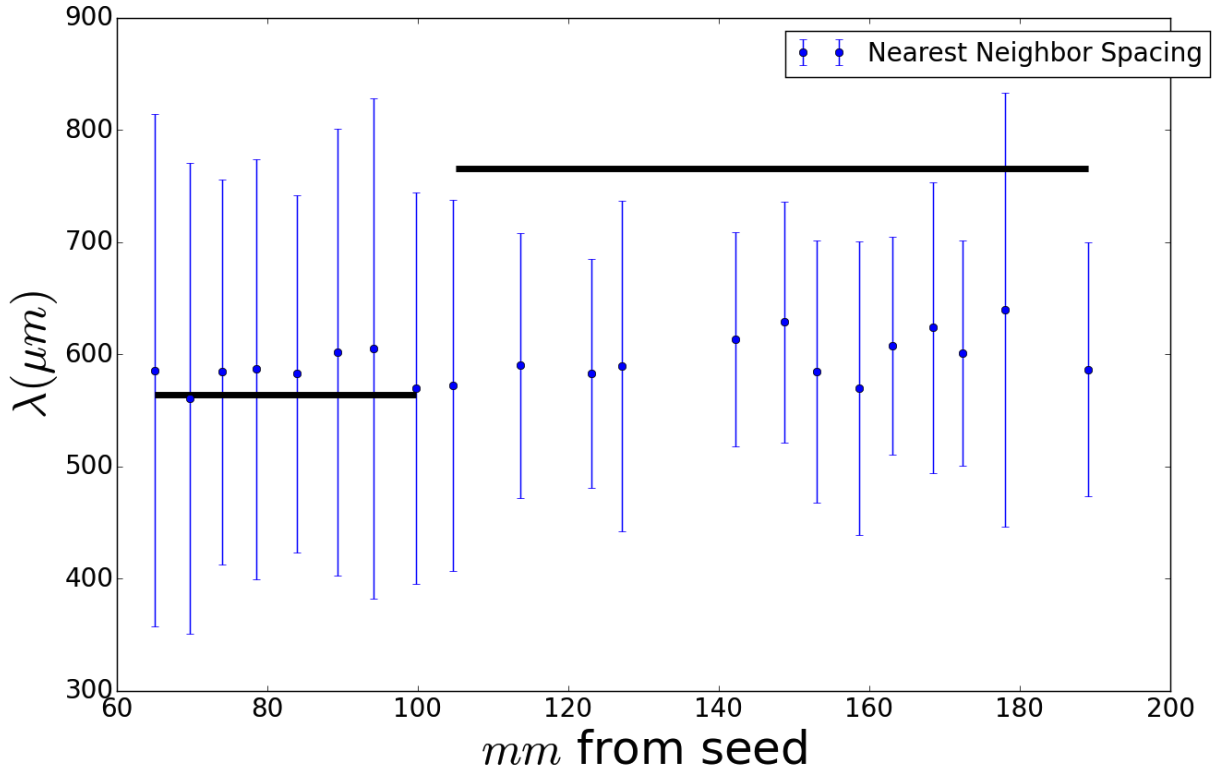


118.1 mm from the seed



149.4 mm from the seed

MICAST7G- Primary Dendrite Arm Spacing



Conclusions

- The primary dendrite spacing increased in microgravity.
- The "array stability limit" of the Hunt and Lu model successfully predicted dendrite arm spacing.
  → Based on nearest-neighbor spacing measurements.
- Comparison of the results implies that dendrite arm spacings respond quicker to growth rate changes in μg than on the ground
- Separation was observed between the crucible and alloy in the ISS sample.
  → Presumed Marangoni convection disrupts steady-state dendrite growth.

Acknowledgments

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